Chapter

Gasification Process Using Downdraft Fixed-Bed Gasifier for Different Feedstock

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Abstract

The use of conventional fuels is decreasing globally due to its limited reserves and negative impact on the environment. The associated cost of conventional fuels is increasing owing to the higher demand for conventional fuels. Hence, utilization methods of biomass to generate energy are of growing interest. Among different biomass feedstocks, rice husks, waste plastics, and sawdust are significantly available in the global environment. The annual generation amount of rice husk is approximately 120 million tons worldwide, with an annual energy generation potential of 109 GJ with a heating value of 15 MJ/kg. The gasification process is assumed to be the most effective biomass conversion method that can generate synthetic gas to operate IC engines, fuel cells, and boilers. Synthetic gas production from biomass using a gasification process is a significant source of future energy. Downdraft fixed-bed gasifiers are considered as a feasible option of biomass conversion in the gasification process. By optimizing the operating conditions of downdraft fixed-bed gasifier, such as reaction zone temperature, combustion zone temperature, intake air temperature, airflow rate, the humidity of intake air, a significant amount of synthetic gas can be produced from rice husks, waste plastic material, and sawdust.

Keywords: gasification, downdraft fixed-bed gasifier, rice husk, waste plastic, sawdust

1. Introduction

1.1 Global energy status

Human civilization and development have significantly increased world energy demand over the past years [1]. Consumption of world energy includes all energy sources consumed by humans in their economy and industrial purposes [2, 3]. Major factors that influence energy consumption are the high growth rate of population and per capita energy consumption. The globalization of international trade is another factor that affects the global energy profile [4]. **Figure 1** shows the global energy consumption from 2000 to 2020 and the forecast of future energy for 2035.

However, the world's population is the main global energy consumer [2–4]. According to the United Nations forecast data, the global population will reach

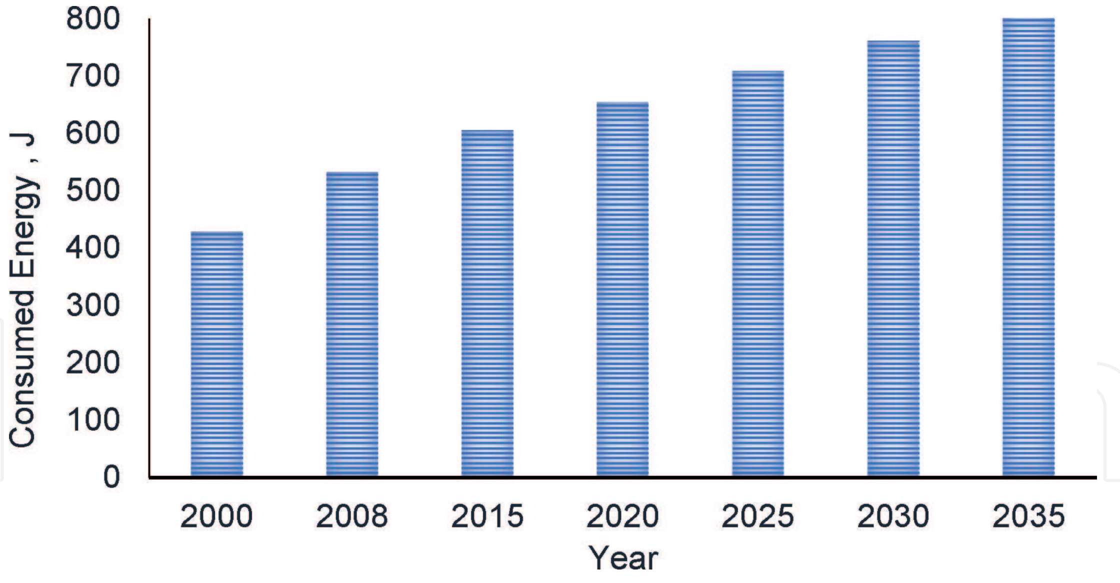

Figure 1.
World's energy consumption scenario [1].

approximately 9.157 billion in 2040, which is around 2 billion higher than the population reached in 2015 [2]. **Figure 2** shows the global population in 2015 and the forecast for 2040. It is a challenge to provide sufficient energy to this huge population of around 2 billion using conventional energy sources.

All countries and regions worldwide are trying to reduce the use of conventional energy sources due to their low reserve and high rates of emission. However, due to the change in overall gross domestic product (GDP), failure of energy-saving technologies, and lack of investment for alternate energy, it is difficult to reduce the intense use of conventional energy. Consequently, the environment is largely polluted, and the world is moving towards an energy crisis era. The major sources of conventional energy are oil (33%), and the other sources of energy are coal provides 27%, and natural gas, 24% [6–8]. On the other hand, hydropower energy sources supply 6%, renewable sources 5%, and nuclear energy sources provide 4% world energy [7]. **Figure 3** presents the world's primary energy consumption sources. Overall around 84% of global energy is consumed from conventional fossil fuels. Therefore, finding new sources of energy is a major concern nowadays. In certain capacities, alternative renewable sources of energy are currently used with conventional fuels [9].

1.2 Renewable energy sources

Renewable energy sources can be utilized to generate energy again and again where wastes are minimized with less air pollution. Renewable sources of energy provide a significant contribution to global energy demand. It includes solar energy, energy from biomass, wind, ocean energy, and hydropower [10]. They supply clean energy and give less pollution than conventional sources of energy. Due to the depletion of conventional fuels and their negative impact on the environment, renewable energy sources would have a remarkable contribution to the world economy [11]. Again, fossil fuels reserve are diminishing, and they create an adverse effect on the environment that causes health hazard and change global climate condition [12]. Hence, the world's population moves slowly towards the generation of energy from sustainable renewable energy sources. **Table 1** shows the global consumption of renewable energy in a million tons of oil equivalent (Mtoe) and their forecast for 2040.

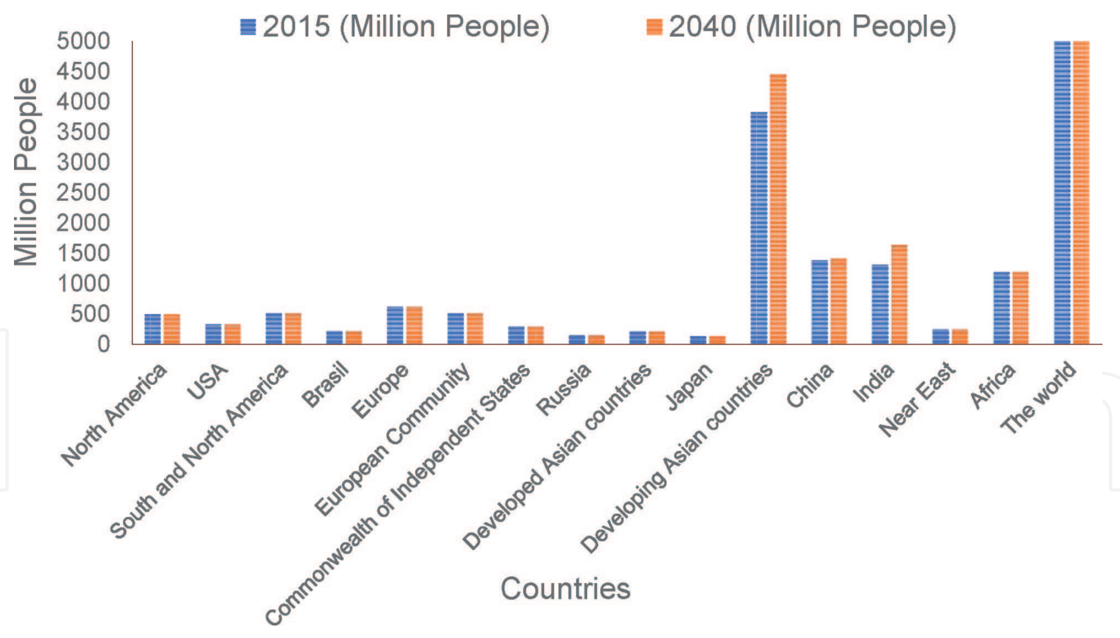

Figure 2.
Global energy population by different countries in 2015 and 2040 [2, 5].

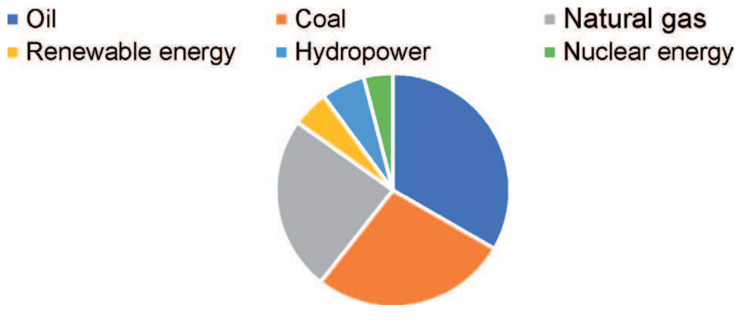

Figure 3.
World's primary energy sources [6–8].

Renewable energy sources	Year				
	2001	2010	2020	2030	2040
Biomass energy	1080	1313	1791	2483	3271
Solar energy	4.10	15.0	66.0	244.0	480.0
Hydropower	22.70	266.0	309.0	341.0	358.0
Wind energy	4.70	44.0	266.0	542.0	688.0
Tidal/wave energy	0.050	0.10	0.40	3.0	20.0
Geothermal energy	43.20	86.0	186.0	333.0	493.0
Consumption of total energy (Mtoe)	10,038	10,549	11,425	12,352	13,310

Table 1.
World's renewable energy consumption scenario in million tonne of oil equivalent (Mtoe) [13].

Overall, renewable sources of energy provide approximately 15% supply of global energy demand [14]. The use of renewable energy sources is now considered an alternate solution to meet the high energy demand [15, 16]. Major sources of renewable energy are solar, biomass, and hydropower. **Figure 4** shows the prospective usage options of renewable energy that can be applied to meet up the global energy demand [17–20].

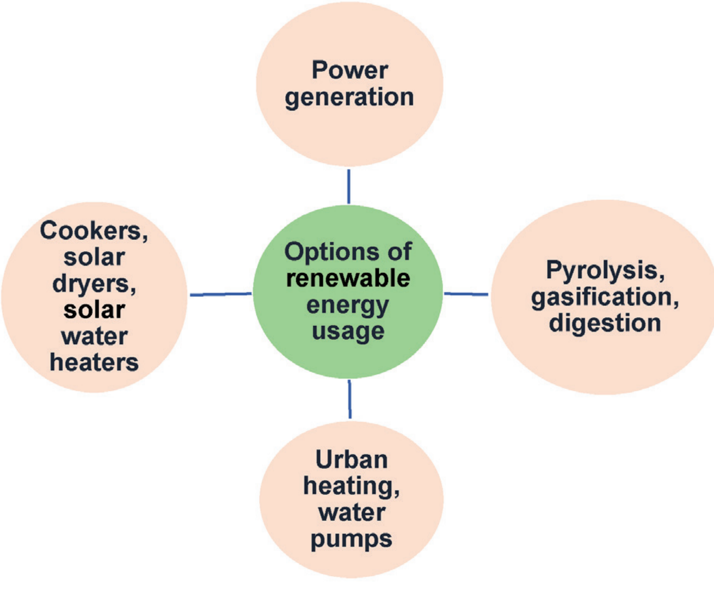

Figure 4.
Options of renewable energy usage [17–20].

Energy generation from solar and hydropower sources are dependent on the weather condition of that country or regions of the world. Among different renewable sources, biomass plants require 0.820–1.130 relative units of energy to generate per unit of electricity, whereas solar photovoltaic requires 0.470 [17]. **Table 2** shows global renewable energy sources with their required relative units to generate per unit of energy.

1.3 Biomass renewable energy

Biomass renewable energy is a significant source of energy that can provide energy at a lower cost. It can maintain a sustainable energy supply and targeted greenhouse gas reduction all over the world. Moreover, energy generation methods related to biomass renewable sources are growing in interest due to the lower reserves of conventional fuels [21]. Also, regulations on low carbon dioxide emissions and reduced pressure on fossil fuels increase the interest in biomass renewable energy sources. Biomass renewable energy sources include waste produced from plants, rice husks, waste plastics, sawdust, algae, and trees [2]. Biomass renewable energy sources are mainly found in the wood form.

Usually, energy can be generated using thermal or chemical processes, as depicted in **Figure 5**. Gasification, pyrolysis, and combustion are the commonly used thermal processes to generate energy from biomass sources. In contrast, by applying chemical reagents and processes, biogas, hydrogen, and ethanol gas is generated from biomass renewable sources [22]. Gasification is now considered as one of the potential conversion processes, and therefore, this chapter presents the gasification methods of biomass sources.

Overall, biomass energy sources supply around 15% of the global energy and 35% for the developing countries. It is an effective bio-renewable energy source that is available globally. Production of biomass is approximately 146 billion metric tons per year globally [22]. It is approximated that 90% of the global population will depend on biomass renewable energy sources by the end of 2050 [22]. **Figure 6** shows the different usage options of biomass renewable energy that can be utilized to solve the high demand for future energy. It is seen from **Figure 6** that biomass renewable energy has the potentiality to use as energy and non-energy sources.

Renewable energy sources	Required quantity to generate per unit of electricity
Biomass energy plant	0.82–0.13.0
Solar PV plant	0.470
Tidal energy plant	0.070
Wind energy plant	0.06–1.920
Wave energy plant Geothermal energy plant	0.30–0.580 0.080–0.370

Table 2.
Energy production from different renewable energy sources plant [17].

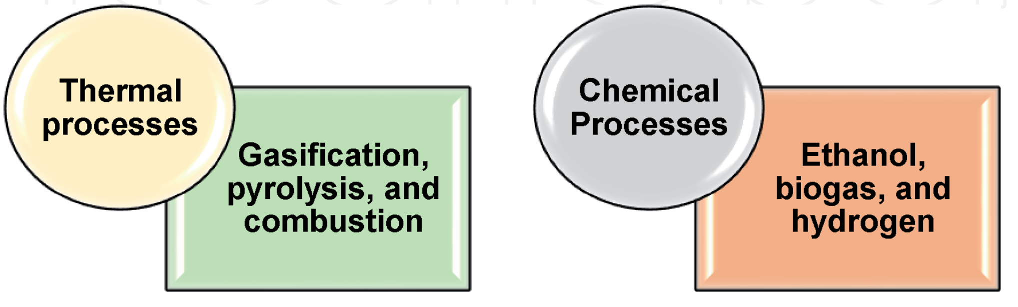

Figure 5.
Different power generation processes for biomass [22].

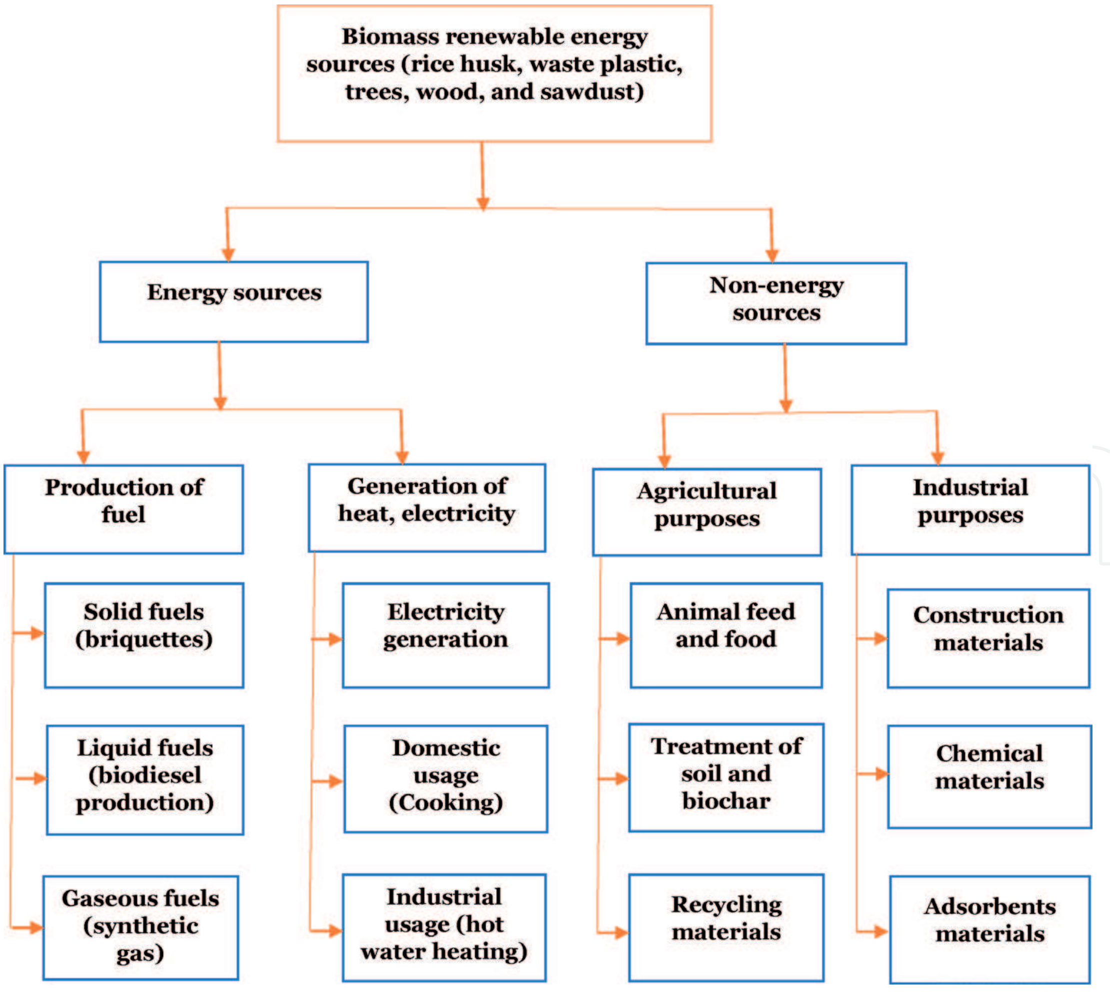

Figure 6.
Different applications of biomass renewable energy [22].

There are different types of biomass sources available in nature. The most common and available biomass sources are rice husk, sawdust, and waste plastics. Rice is the common food among the world's population. Hence, each year, millions of rice husks are wasted all over the world. On the other hand, plastics are used with a high growth rate due to their formability and higher durability. Therefore, turning waste plastic to generate energy is a potential way that can generate energy and reduce global environmental pollution. Sawdust can also be converted into energy using biomass anaerobic gasification method [23].

This chapter also presents the salient features and gasification method using a downdraft fixed-bed gasifier. It has been found in previous literature that the upper limit of moisture content of downdraft fixed-bed gasifier is 25% on a wet basis, while for updraft fixed-bed gasifier, it is 50% on the wet basis of measurement [24]. However, the high content of feed moisture negatively affects the gasification process and product gas [25, 26]. As a consequence, downdraft fixed-bed gasifier may provide better performance than updraft fixed-bed gasifier. Hence, this chapter considers the performance analysis of the downdraft fixed-bed gasifier.

2. Conventional biomass conversion technologies

2.1 Gasification

Gasification is the method that can convert carbonaceous biomass material to hydrogen, carbon dioxide, and carbon monoxide [27]. The method can be achieved by reaction of feed material at over 700 °C temperature, with a limited amount of oxygen and steam. In the gasification method, the feed material is processed without combustion. In this method, the generated mixture of gas is considered synthetic gas or producer gas utilized as fuel [28]. The produced power in the biomass gasification method and combustion of the generating gas can be considered as renewable energy source.

In chemical reactions of gasification method, char type carbonaceous feed material (C) is reacted with steam (H_2O) and generates carbon monoxide (CO) and hydrogen (H_2).

$$C + H_2O \rightarrow H_2 + CO \quad (1)$$

$$C + CO_2 \rightarrow 2CO \quad (2)$$

Therefore, in the gasification method, a small amount of air or oxygen is applied to the gasifier reactor to burn the organic feed material to generate energy and carbon dioxide. **Figure 7** shows the overall process of the gasification method to generate synthetic gas.

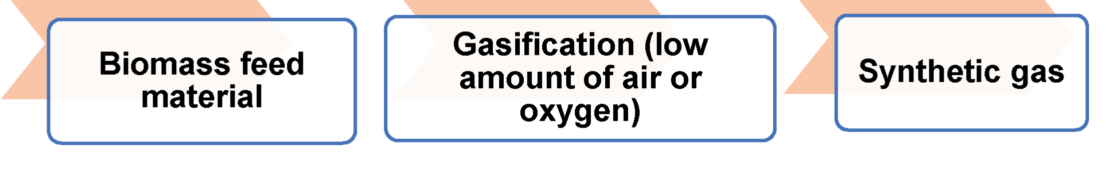

Figure 7.
Flow diagram of biomass gasification process [29].

The gasification method of biomass renewable energy sources is the potential sources to generate energy, chemical energy, and biofuels. A gasifier is required to convert biomass renewable energy sources to synthetic gas in the gasification method. The generated synthetic gas is used to operate an internal combustion engine. They can also be used to produce electricity and heat energy by using a cogeneration system [30].

Again, the gasification process of biomass renewable energy sources is similar to the coal gasification method. Thermal decomposition of both biomass and coal gasification method generates the same output gases [31]. However, the operating conditions of gasification methods of biomass energy sources are less severe than coal gasification method [32]. In the biomass gasification method, cellulose and hemicellulose present in the feed material, whereas carbon is the main material of coal feed materials.

Practically, biomass energy sources are required to dry first. After that, the dried feed materials are required for the process of shrinkage and devolatization [30]. Finally, the char gasification is applied from the surface of the material to the biomass center. **Figure 8** shows the overall process of biomass gasification to generate energy.

The overall power generation cost of the gasification process of biomass renewable energy includes labor cost 54%, cleaning cost of synthetic gas 28%, balancing of plant 9%, fuel cost 6%, and miscellaneous cost 3%. **Figure 9** represents the overall power generation cost of gasification methods.

2.2 Pyrolysis

Pyrolysis is the process where biomass materials are decomposed in absence of air or oxygen using heat energy. Therefore, the pyrolysis method generates bio-char as solid fuels, bio-oil as liquid fuels, and gases (non-condensable) [35]. **Figure 10** shows the overall process of pyrolysis method. The pyrolysis oil properties and yield of pyrolysis products depend on the operating conditions and parameters of the pyrolysis process. The pyrolysis process's operating parameters are the heating rate of feed material, the temperature of the reactor, residence time, catalysts, and reactor configurations.

The Pyrolysis process of biomass renewable energy sources can be simplified by the following Equations [36]:

$$\text{Biomass feed materials} \rightarrow H_2O + \text{unreacted residue materials} \tag{3}$$

$$\text{Unreacted residue materials} \rightarrow \text{Volatile materials} + \text{Gases} + \text{bio} - \text{char.} \tag{4}$$

$$\text{Bio} - \text{char} \rightarrow \text{Volatile materials} + \text{Gases} + \text{Bio} - \text{char.} \tag{5}$$

Firstly, in the biomass pyrolysis method, feed materials are decomposed to remove the moisture contents and break the bond to form CO, CO_2, and residues [37]. The remaining compounds are exposed to further conversion using cracking and polymerization that produces secondary char, tar, and gases [37]. In this method, at a lower temperature, such as less than 500 °C temperature, the organic vapor materials are not cracked. However, at higher temperatures, they convert readily with fewer residence times. The optimum temperature to generate the maximum quantity of bio-oil using the biomass pyrolysis method is over 500 °C.

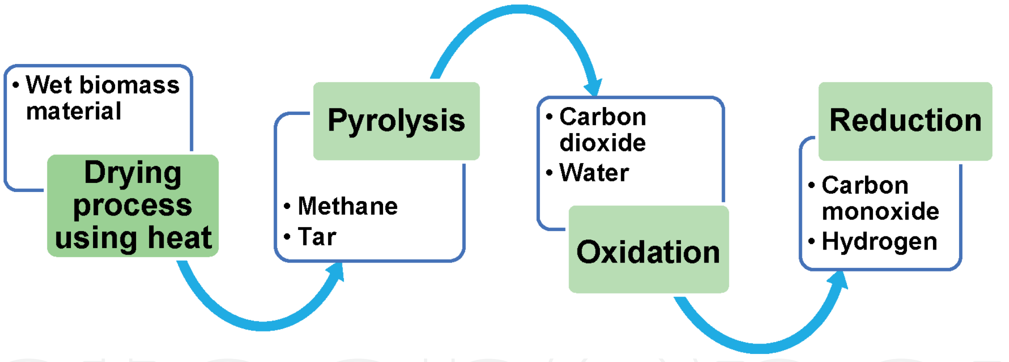

Figure 8.
Energy generation process from biomass gasification method [33].

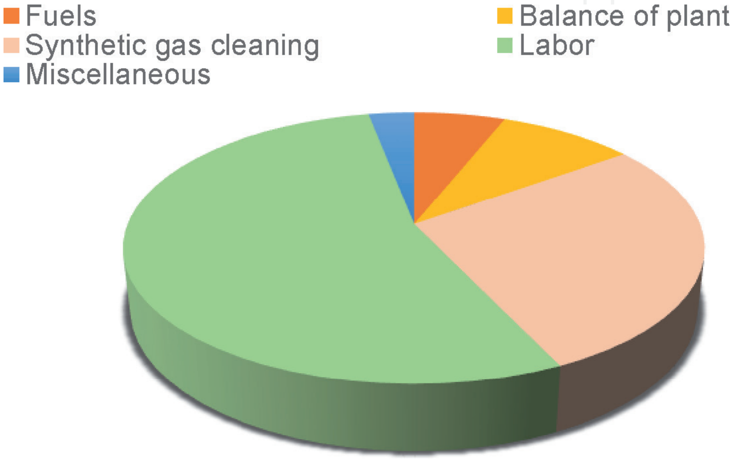

Figure 9.
Power generation cost of biomass gasification method [34].

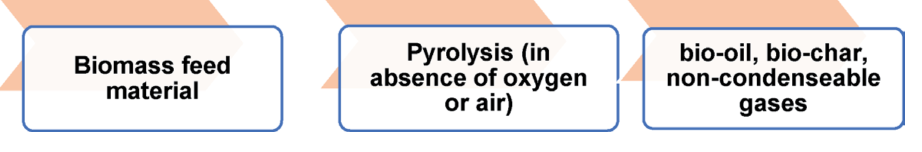

Figure 10.
Flow diagram of pyrolysis methods [35].

The residence time of vapor materials and heating rate in the pyrolysis method can be classified into three major groups, as shown in **Figure 11**.

Fast and flash pyrolysis process generates lower amounts of char when compared with slow pyrolysis process. Flash and fast pyrolysis methods can produce bio-oil in high quantity. Hence, they are considered as a favorable method for the generation of bio-oil [35].

Slow pyrolysis is the process that occurs under a long residence time, lower temperature, and slow heating rate. In the slow pyrolysis method, cracking of the primary material generates a high yield of char.

Slow pyrolysis is the process that occurs under a long residence time, lower temperature, and slow heating rate. In the slow pyrolysis method, cracking of the primary material generates a high yield of char [40, 41]. The remaining non-condensed gases are used for drying purposes of raw biomass materials or as fuel gases. They can also be reflowed to the pyrolysis reactor to heat the pyrolysis method. Overall, biomass fast pyrolysis generates bio-oil (60–75%), bio-char (15–25%), and gaseous yield (10–20%) [42]. This process is preferable compared

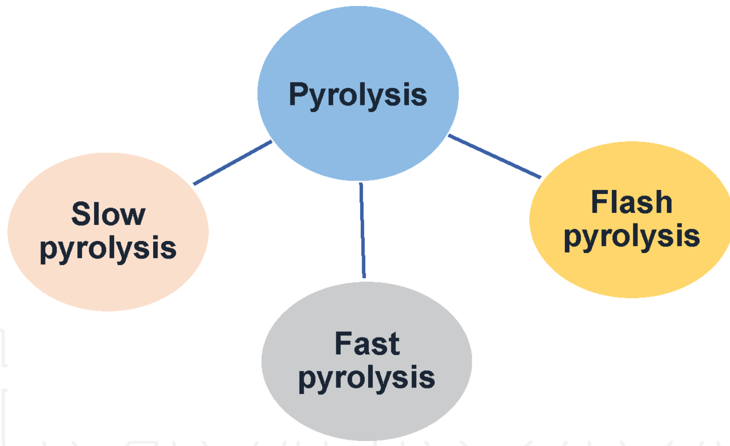

Figure 11.
Types of biomass pyrolysis methods [38, 39].

to the slow and flash pyrolysis method based on the cost, transportability, and storability of liquid and gaseous fuels.

Flash pyrolysis is the third major group of pyrolysis methods that sometimes refer to a similar fast pyrolysis process. However, the flash pyrolysis method generates pyrolytic yield under a high heating rate, higher reaction temperature values, and short residence time [35]. This method has the capability to generate a high quantity of bio-oil from the conversion of biomass feed material. It has the capacity to convert a higher quantity of biomass to liquid bio-oil. However, the generated bio-oils in the flash pyrolysis method are unstable, acidic, and highly viscous in nature [43]. They even also contain solids and dissolve water. Hence, the yields of the flash pyrolysis method require up-gradation methods, such as hydrogenation and catalytic cracking to reduce the final product's oxygen content. **Table 3** shows the operating variables require to operate slow pyrolysis, fast pyrolysis, and flash pyrolysis method.

The pyrolytic reactor is considered the heart of the pyrolysis method and based on the types of reactors; the yields would change in the pyrolysis method. Several pyrolysis reactors are used in the pyrolysis process, such as a fixed-bed reactor, fluidized bed reactor, moving bed reactor, suspended bed reactor, inclined rotating bed reactor, etc. However, fixed and fluidized beds are commonly used in pyrolysis reactors. A fixed-bed reactor usually uses an external heating source by using a furnace. In contrast, the fluidized bed reactor uses a solid–fluid mixture of stable reactor bed where nitrogen is used to create an inert atmosphere. **Figure 12** shows the characteristic properties of a fixed-bed and fluidized bed reactor. Fluidized bed reactors are easy to operate, capable of transferring high heat rates, good at controlling temperature [44, 45]. Therefore, the pyrolysis method is an effective way of biomass to the energy conversion process.

2.3 Incineration

The process when the combustion of biomass materials occurs to generate heat, ash, and flue gases is known as incineration, as shown in **Figure 13** [46]. It is considered as the thermal treatment process of biomass materials. In this process, ash is produced due to the inorganic components contained in the biomass feed material. Ash and flues gases are required to clean, whereas the generated heat in the incineration process produces electricity. In recent practice, the generated heat is used to produce electricity effectively using combined heat energy and power systems. However, emission control is the main factor that needs to be considered during the biomass incineration process [30].

Types of pyrolysis method	Temperature (K)	Rate of heating (K/sec)	Residence time in sec	Size of particles (mm)
Slow	550–950	0.1–1	450–550	5–50
Fast	850–1250	$500–10^5$	0.5–10	Less than 1
Flash	1050–1300	Above 10^5	Less than 0.5	Less than 0.2

Table 3.
Operating variables for fast, slow, and flash pyrolysis method [37, 42].

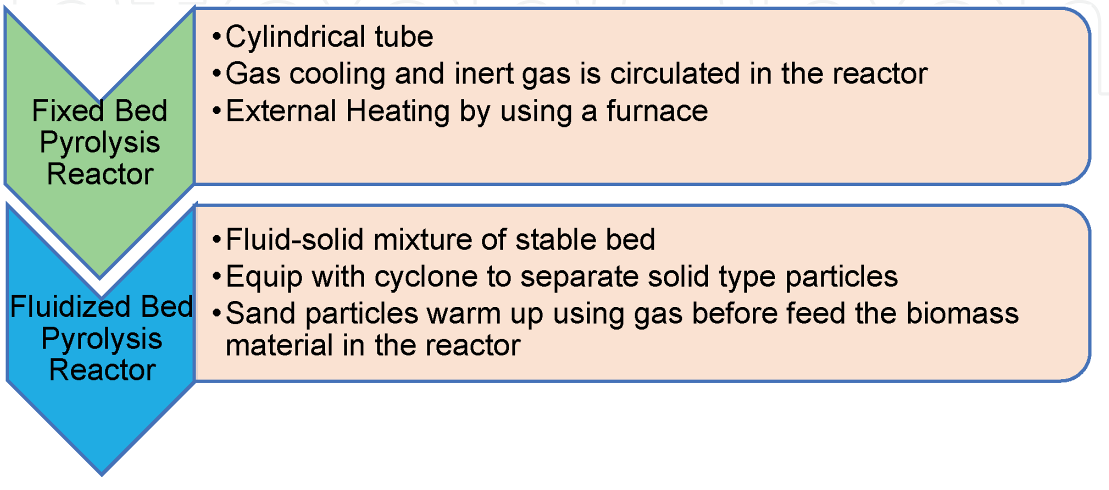

Figure 12.
Major types of reactor use in pyrolysis method.

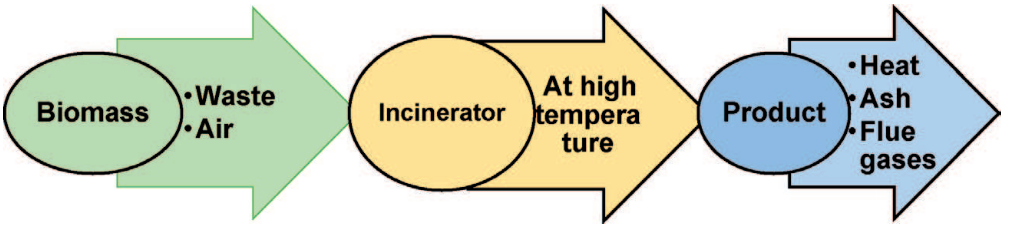

Figure 13.
Biomass incineration process [47].

The incineration process is one of the several energy generation methods from wastes. Although gasification and incineration methods are considered similar, the generated energy is not the same for them. In the gasification method, combustible gas materials are the major energy product, whereas high-temperature heat is the main energy component in the incineration method [47, 48]. Both the gasification and incineration methods can be implemented without the recovery of energy.

3. Gasification method using different gasifiers

In the biomass gasification method, a gasifier is the core of the mechanism. There are different types of gasifiers commonly used in the gasification method. They can be classified depending on the ratio of dense phase biomass to the reactor's total volume. Therefore, dense phase gasifiers and lean phase gasifiers are two common types of gasifiers use in the gasification process. Dense phase biomass gasifiers have a density factor of between 0.08 to 0.3, whereas lean phase gasifiers' density factors vary between 0.05 to 2 [30, 49–51].

3.1 Counter-current or updraft gasifier

In counter-current or updraft gasifiers, the air or oxygen is passed through the gasifier's bottom level, and the generated product gases are left at the top of the gasifier [52]. Combustion reactions occur at the bottom side of the gasifier near the grate. After that, the reduction reactions occur at the somewhat upper level of the combustion zone, as shown in **Figure 14**. In the upper level of updraft gasifier, pyrolysis process and heating of the biomass materials occur using the forced convection and radiation heat transfer methods where the required heat is provided from the combustion and reduction zone in the lower part of the gasifier [53]. The generated volatile matters and tars in the updraft gasifier carry in the upper-level gas stream, as depicted in **Figure 14**. On the other hand, produced ash require to clean from the bottom layer of the updraft gasifier.

The main advantages of an updraft gasifier are simplicity in design, simplicity in operation, lower exit gas temperature, and high burning rate of feed materials. Therefore, the equipment efficiency of the updraft gasifier is high. This type of gasifier can be operated using different feed materials such as rice husk, waste plastics, and sawdust.

On the other hand, the disadvantages of updraft gasifiers are channeling that breaks the air or oxygen and creates harmful or explosive situations. Therefore, automatic grates are required in the updraft gasifier. Disposal of tar is another disadvantage in the case of an updraft gasifier.

3.2 Co-current or downdraft gasifier

In a downdraft gasifier, air or oxygen generally enters the middle zone of the downdraft gasifier above the grate, as presented in **Figure 15**. Air or oxygen enters at or above the oxygen region level in the downdraft gasifiers [54]. The feed materials are entered at the top of the gasifier, similar to the updraft gasifier. However, air and

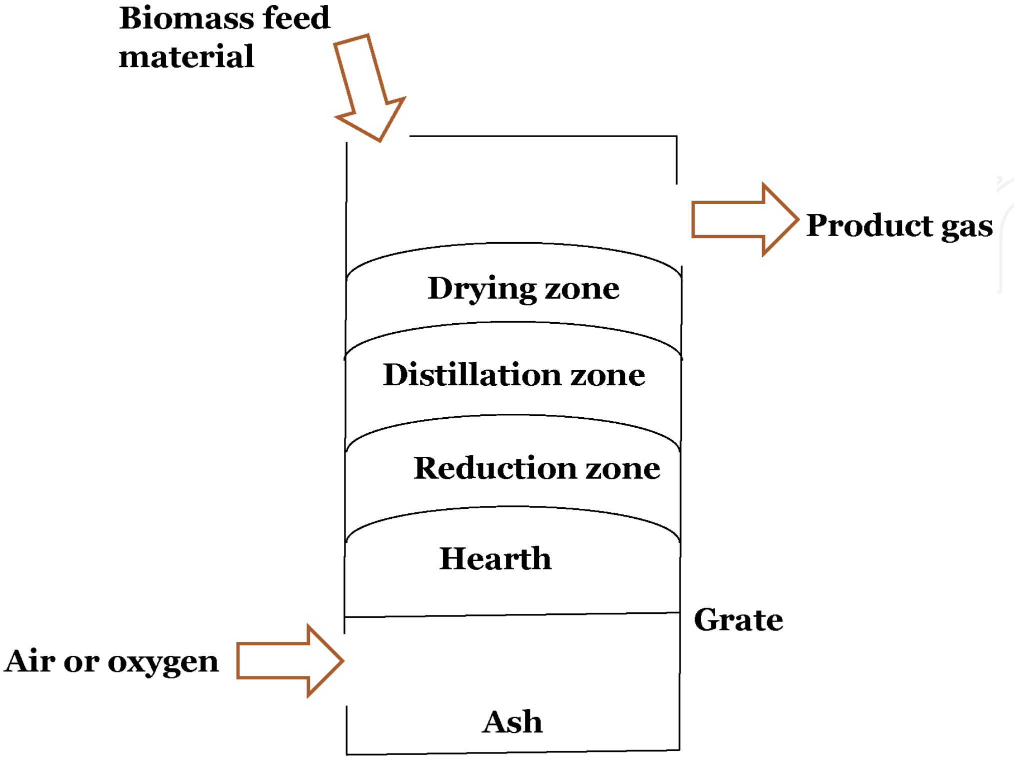

Figure 14.
Gasification process using updraft gasifier [54].

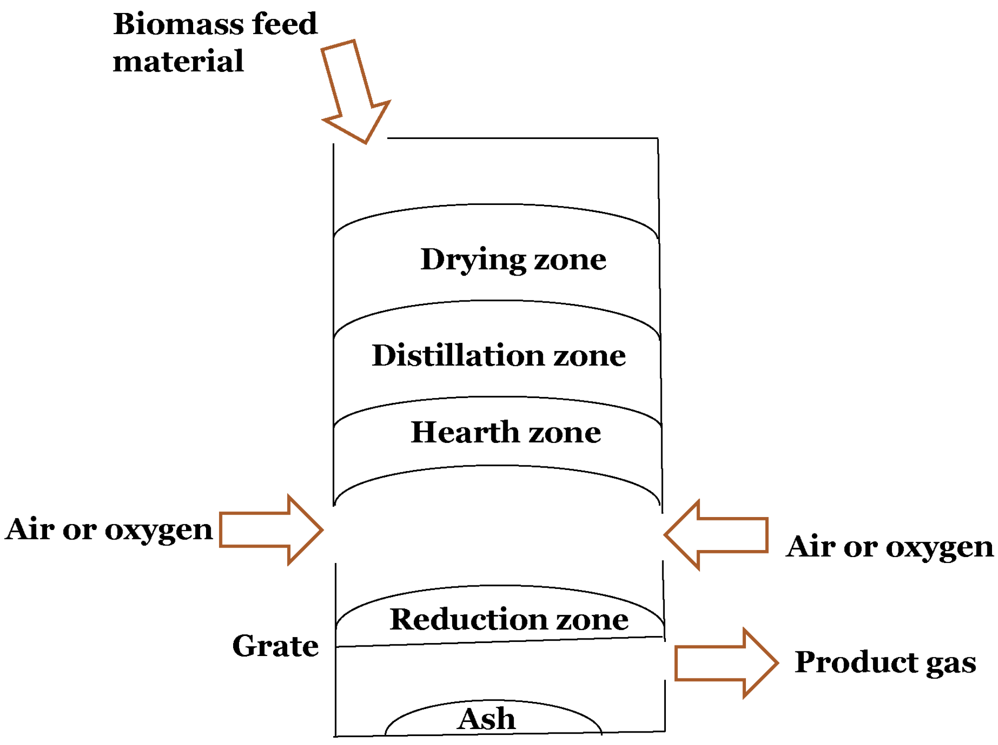

Figure 15.
Gasification process using downdraft gasifier [54].

generated gas mixtures are passed through the oxidation region. In a downdraft gasifier, the producer gases are removed at the bottom level of the gasifier. Therefore, gases and fuels in co-current or downdraft gasifiers are moved in the same direction. When the gases and fuels move down, the fuel must pass through a charcoal bed and generate H_2, CO, CO_2, and CH_4. In a downdraft gasifier, based on the hot region temperature and residence time of tars, most of the tars are broken down. Therefore, the generated product gas in co-current or downdraft gasifier contains lower tar than updraft gasifier. Consequently, they are suitable to use in an internal combustion engine compared to the updraft gasifier gases.

The major advantages of downdraft gasifiers are tar-free gases, and they are suffered less from the environment compared with updraft gasifiers. **Figure 16** shows the salient features of the co-current or downdraft gasifier.

The main disadvantage of co-current or downdraft gasification is the inability to utilize or operate unprocessed fuel. Downdraft gasifier is suffered much from the high content of ash materials when compare with updraft gasifier.

3.3 Fluidized bed gasifier

In a fluidized bed gasifier, fuel fluidizes with air or oxygen and steam. Fuel is fed into a bubbling or circulating type fluidized bed. The bed of fluidized bed gasifier acts as fluid with high turbulence. In this system, ash materials are removed from the gasifier in a dry state that defluidize. The temperature in a fluidized bed gasifier is low, and the fuel is required to be highly reactive [55, 56]. However, the energy conversion efficiency is lower than the downdraft gasifier due to the elutriation of carbonaceous fuel [57]. There are three major types of fluidized bed gasifiers: circulating, bubbling, and dual fluidized bed.

The working principle of the operation of updraft and downdraft gasifier is affected by the fuel's chemical and physical properties. Fluidized bed gasifiers can solve a few of the drawbacks of updraft and downdraft gasifiers, such as pressure drop and low bunker flow over the updraft or downdraft gasifier [58].

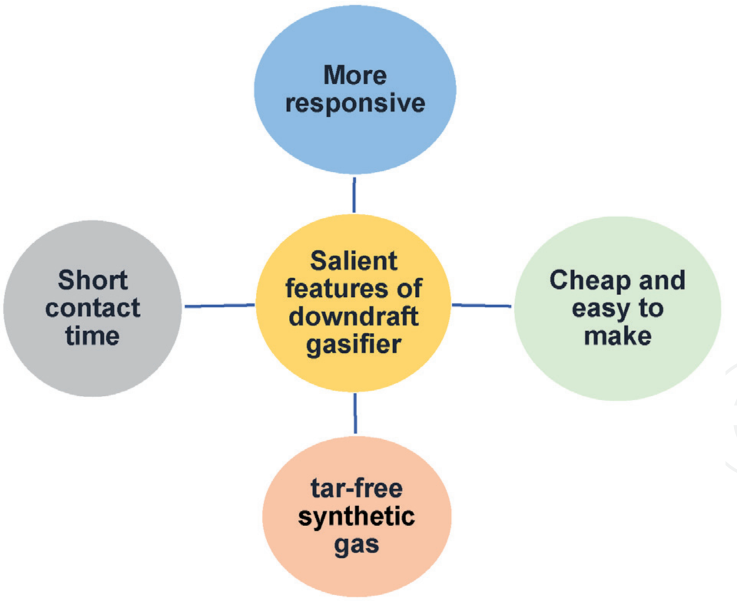

Figure 16.
Salient features of the gasification process using downdraft gasifier.

Overall, a fixed-bed gasifier has the capacity for a wide range of temperature distribution. On the other hand, a fluidized bed gasifier can transfer heat between solid and gaseous phases with the best temperature distribution. Fluidized bed gasifiers can tolerate a high variation of fuel quality as well as a large particle distribution [58]. The major drawbacks of fluidized bed gasifiers are high dust contents that make the conflict between higher reaction temperatures with better energy conversion efficiency and lower melting temperature of ash.

3.4 Entrained flow gasifier

In an entrained flow gasifier, a dried solid pulverized, liquid fuel, or a slurry of fuel is reacted with oxygen or air in a gasification process using co-current flow [59]. In an entrained flow gasifier, gasification reactions are taken place in a dense cloud of fine particles. High throughput can be achieved, but the overall efficiency is relatively low than the downdraft or fluidized bed gasifier. The entrained flow gasifier system's residence time is approximately 5 seconds that is shorter than the residence time of the downdraft or fluidized be gasifier. Most of the reactions of entrained flow gasifiers are endothermic. Therefore, high heat is required to be supplied using combustion of biomass feed material or from the outside sources of heat.

In this gasifier, finer coal with air is added co-currently in such a way that air and water steam surrounds the finer coal feed materials. This type of gasifier usually operates at very high pressure and temperature [60]. As a consequence, the flow is turbulent in an entrained flow gasifier. The rate of gasification reaction and efficiency of conversion of carbon is high, while the generation of hydrocarbons is low. Moreover, the coal devolatization process generates oil, tar, other liquids, and phenols that can be decomposed into hydrogen (H_2). This chapter describes gasification of rice husk, waste plastic, and sawdust biomass, therefore the entrained flow gasifier performance is not presented with their related analysis.

3.5 Plasma gasifier

In a plasma gasifier, high voltage and current are applied to a torch that can create an arc of high temperature. In the gasification method using plasma gasifier, inorganic components of feed material are converted into a glass-like substance. It can also be used to gasify solid wastes mainly generated from municipal and households [61].

The plasma type gasifier mainly heats up by using a torch of plasma that is usually located at the bottom of the reactor [62]. At atmospheric pressure, feed materials are required to add to the reactor. The majority of the plasma gasifier is water-cooled on the outer side of the gasifier. In the gasification process of plasma gasifier, the generation of tar is usually eliminated by maintaining the temperature of the synthetic gas greater than 1000 °C.

4. Different biomass feedstock materials

In the gasification method, carbonaceous materials such as rice husk, coal, waste plastics, and sawdust are turned into synthetic gas in the presence of limited air or oxygen, carbon dioxide, and steam. The generated synthetic gas includes hydrogen (H_2), carbon dioxide (CO_2), carbon monoxide (CO), Nitrogen (N_2), char, tars, ash, and bio-oil [63].

This chapter presents the gasification of rice husk, waste plastic, and sawdust as biomass feed material due to their availability, high production rate, and reduction of environmental pollution. The majority of the world population use rice as their main food. Therefore, it was estimated that rice husk generation globally is about 80 million tons with an annual energy generation potential of 1.2 ~ 109 GJ. The estimated heating value of rice husk is approximately 15 MJ/kg [18]. In Asia and Africa, the annual generation of rice husk is 1.5×10^{11} kg [64].

On the other hand, the world's population uses plastic material in their daily activities due to its insolubility in liquid water, availability, resistance to corrosion, and lighter weight. The generation of plastic waste materials is increasing globally. For example, Asia regions possess maximum plastic waste, and they generate around 30% of plastic wastes in the world [65]. Therefore, if the plastic waste materials can be used as biomass feed material in the gasification method to generate energy, the waste materials are turned into energy. On the other hand, world environmental pollution due to waste plastics will also be reduced significantly. Waste plastic material can also be converted into oil by using fast pyrolysis.

Sawdust material is another potential biomass source use in the gasification process. Carbonaceous feed materials are effective for gasification methods. The ultimate and proximate analysis of sawdust material shows that sawdust contains approximately 50.90% carbon. **Table 4** shows the ultimate analysis results of rice husks, sawdust, and waste plastic material.

Biomass feed materials	Carbon C (%)	Oxygen O (%)	Nitrogen N (%)	Hydrogen H (%)	Sulfur S (%)
Rice husk [66]	45.2	47.6	1.02	5.8	0.2
Waste plastic [67]	77.10	11.20	0.20	11.50	—
Saw dust [23, 68]	50.9	45.03	0.27	3.7	0.05

Table 4.
Ultimate analysis of rice husk, waste plastics, and sawdust biomass feed materials.

5. Gasification method using downdraft gasifiers

Downdraft fixed-bed gasifiers generate low tar content synthetic gas that can be used to operate an internal combustion engine. Hence, this chapter presents the gasification methods using the downdraft fixed-bed gasifier.

5.1 Gasification performance

The performance of the gasification method mainly depends on the reactor temperature. With an increase in reactor temperature, the performance and yield of the gasification method are also increased. It was observed that with waste plastic gasification method using downdraft gasifier, at 600 °C synthetic gas yield was 112.4 (wt. %), whereas at 700 °C yield was 166.8% (wt. %), 800 °C generated 205.7% (wt. %) gaseous yield and maximum synthetic gaseous yield obtained at 900 °C (234.6 wt. %) [67].

In rice husk and sawdust gasification method, the performance of synthetic gas yield generation also depends on the reactor temperature. It was obtained that using a total 5 kg rice husk with 3.6 kg/h feed rate for 1.38-hour gasification in a downdraft fixed-bed gasifier; the generated synthetic gas yield was highest at 810 °C (0.27 wt.% CH4 and other gases 61.09 wt.%) [18].

Catalytic temperature is another significant parameter of the biomass gasification method. With the increase of reactor temperature and catalytic temperature in the sawdust gasification method, the synthetic gas yield is also increased. It was found that at a constant gasification temperature of 800 °C in a downdraft fixed-bed gasifier, the synthetic gas yield was 63.43 (wt. %) at 600 °C catalytic temperature. In contrast, the gas yield was 71.35 (wt. %) at 700 °C catalytic temperature, 77.25 (wt. %) at 800 °C catalytic temperature, and 80.58 (wt. %) at 900 °C catalytic temperature [68].

5.2 Synthetic gas composition

In this chapter, gasification method using downdraft fixed-bed gasifier generates synthetic gas from rice husk, waste plastic, and sawdust biomass energy sources. Among different gases, carbon monoxide, carbon dioxide, methane, hydrogen are significant. Carbon dioxide and carbon monoxide form a significant portion of synthetic gas, whereas methane generation is lower than carbon dioxide and carbon monoxide [18]. In the case of biomass feedstocks, the generation of H_2 and methane is higher for sawdust than rice husk biomass due to its higher heating value. In contrast, the heating value of plastic is higher than sawdust and rice husk. Therefore, it has a significant potential for H_2 (3–18 vol. %) rich and high methane synthetic gas generation using a downdraft fixed-bed gasifier. On the other hand, the gasification of plastic generates a high quantity of tar that reduces the efficiency of the gasification process. In addition, endothermicity is another drawback of the plastic gasification process. Overall, the gasification process using plastic material is still uncommon in practical cases although the efficiency can be improved by adding another feed material with plastic material as co-feedstocks.

5.3 Power generation using gasifier

The generated synthetic gas from the gasification of rice husk, waste plastic, and sawdust is collected from the exhaust end by controlling the exhaust valve of the downdraft fixed-bed gasifier. A gas analyzer is needed to analyze the contents of synthetic gas. The generated synthetic gas can be utilized to operate the engine, boiler, etc. It is possible to operate any prime movers, such as engines and boilers by connecting them at the exhaust end of a downdraft fixed-bed gasifier where the gasification of rice husk, sawdust, and waste plastic occurs.

The heating value of rice husk, sawdust, and waste plastic is 16.7 MJ/kg, 18.23 MJ/kg, and 40 MJ/kg, respectively.

However, in the biomass gasification method using downdraft fixed-bed gasifier, the heating value is within the range of 5.4 MJ/m^3 to 5.7 MJ/m^3 [69]. The generated synthetic gas from the biomass gasification method can also be used in diesel engines, dual-fuel engines, and petrol engines. Moreover, the produced heat in the rice husk, waste plastic, and sawdust gasification process can be used to generate electricity in an off-grid area. The typical size of an off-grid electricity system is 10–500 kW for the generated heat in these biomass gasification process [30]. The exact size of the off-grid energy system depends on the amount of feedstock materials use in the downdraft gasification process.

6. Conclusion

Rice husk, waste plastic, and sawdust were used as feedstock materials in the gasification process using a downdraft fixed-bed gasifier. The generation of synthetic gas depends on the heating value of biomass feedstocks. It has been found that waste plastic has the highest heating value (40 MJ/kg) among the three biomasses. Therefore, it has the highest potential of H_2 rich (3–18 vol. %) synthetic gas generation than rice husk and sawdust biomasses. On the other hand, sawdust produces a high H_2 and methane content synthetic gas than rice husk. Moreover, the generation capacity and quantity of biomass gasification method depends on the type of gasifier. Downdraft fixed-bed gasifier is one of the effective gasifiers used in the gasification process. The generation of synthetic gas and heat from the biomass gasification method using a downdraft gasifier depends on the reactor temperature, residence time, catalytic temperature, and gasification duration.

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